Reinforced HE Fills for Gun Launch

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Motivation

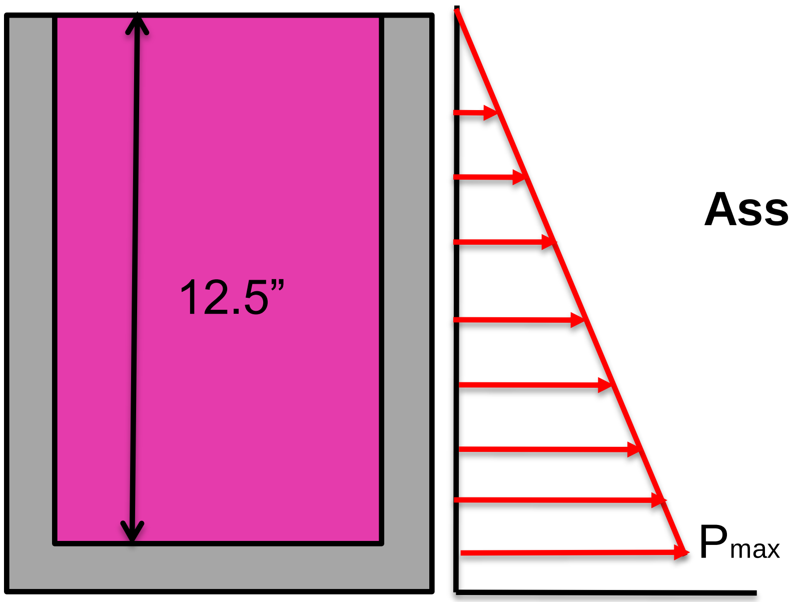
Reinforced HE fills may be required if one or more of the following is true:

- Setback acceleration is extreme(1)
- Fill material density is high
- Fill material strength is weak
- Fill material bonds poorly to sidewall
- A minimum mass of HE is required necessitating a reduction in warhead sidewall thickness
- Warhead sidewall burst strength is low

Reinforced HE fills may be required if the warhead sidewall is unable to support the HE fill during gun launch

(1) Burns, B. P., "Positive Approaches for reducing the in-bore axial launch stress in projectile high explosive fills," ARBRL-MR-03055, Aug 1980.

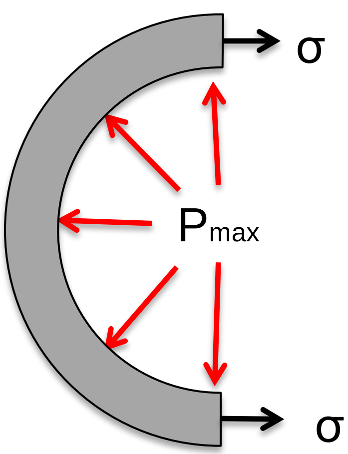
Initial Design Problem



HE fill is a dense, weak, and soft material

Assume HE is a fluid to approximate pressure loading on the sidewall

For assumed max density of 0.234 lb/in^3 (6.5 g/cc) the resulting max pressure is 38 ksi under 13 kG setback



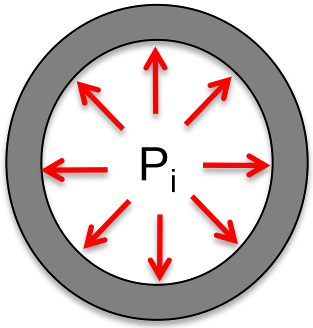
This pressure loads the sidewall and results in the hoop stress σ, the critical design parameter.

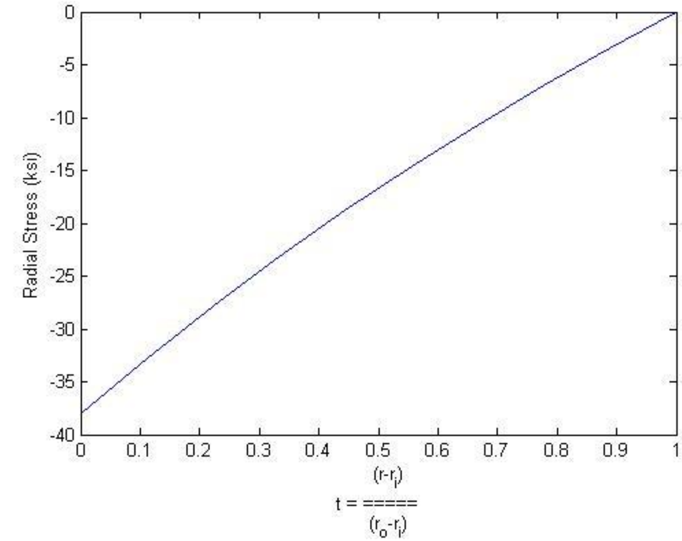
A considerable amount of hoop-strength and/or thickness is needed to resist this large internal pressure

Lame Analysis

<u>105 mm Munition</u>

r_i = 1.75 in.
r_o= 2.00 in.
P_i = 38 ksi
P_o= 0 ksi

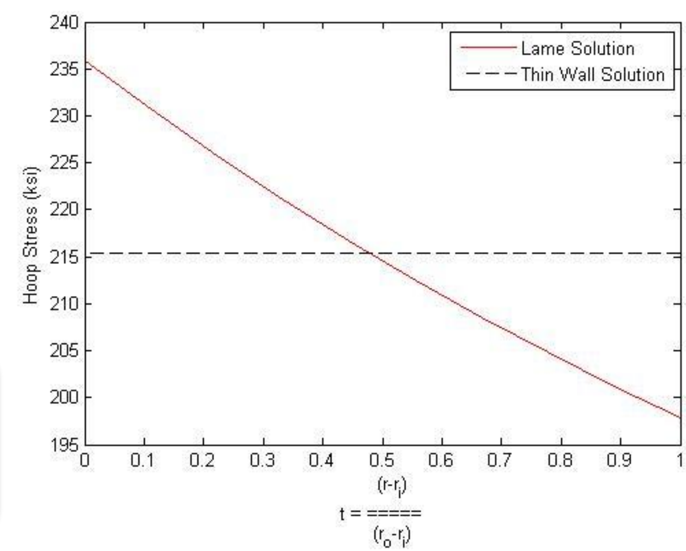




Lame's Equations simplify to (P_o= 0)

$$\sigma_r = \frac{-r_i^2 r_o^2}{(r_o^2 - r_i^2)} \frac{P_i}{r^2} + \frac{r_i^2}{(r_o^2 - r_i^2)} P_i$$

$$\sigma_h = \frac{r_i^2 r_o^2}{(r_o^2 - r_i^2)} \frac{P_i}{r^2} + \frac{r_i^2}{(r_o^2 - r_i^2)} P_i$$

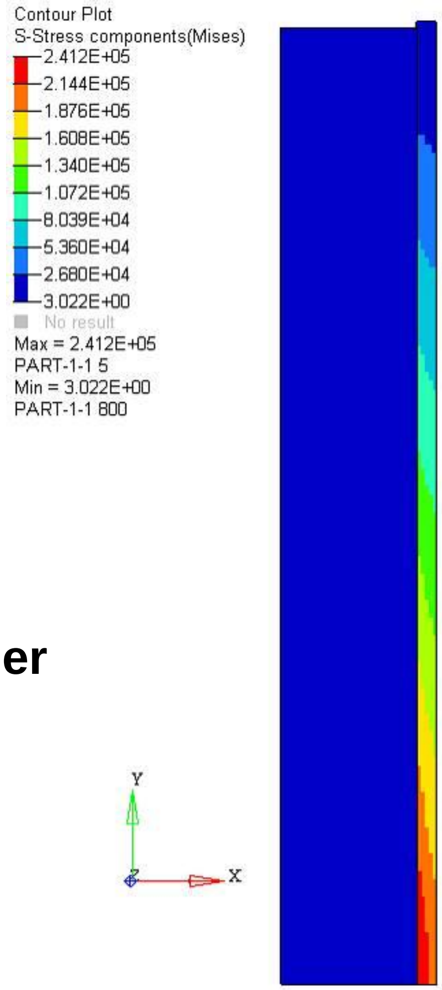


Hoop stress is a order of magnitude greater than radial stress

FEA Verification

HE fill properties for elastic-perfectly plastic material model

- density ρ = 0.234 lb/in^3 (6.5 g/cc)
- elastic modulus E = 1.4 Msi
- yield strength σ = 4000 psi

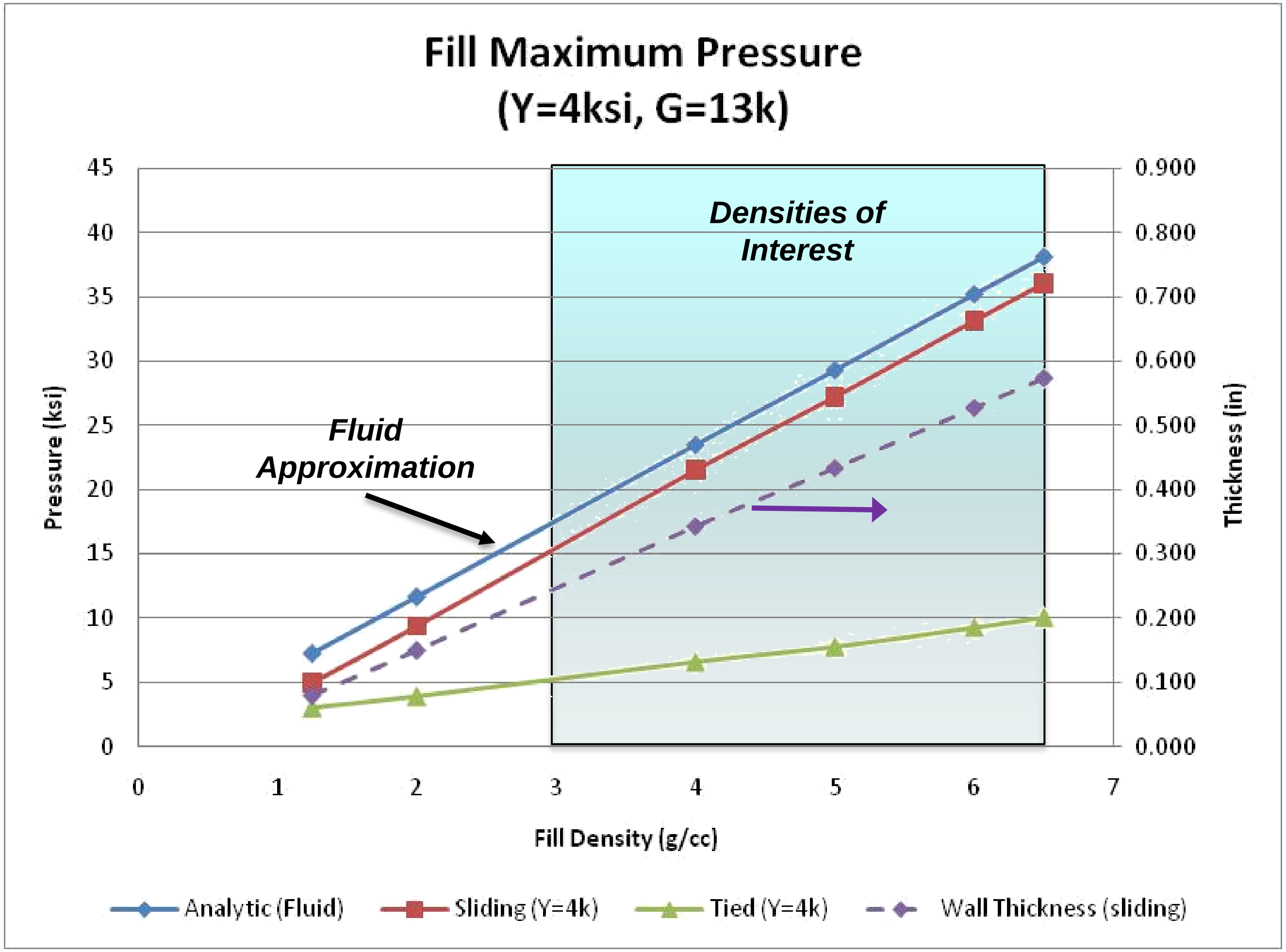


2 Boundary Conditions Considered

- Perfectly bonded - HE fill is permanently bonded to sidewall
- Sliding contact – HE fill is permitted to slide relative to sidewall

FE results indicate that the maximum produced pressure under 13 kG is more severe for the sliding contact boundary configuration than the tied contact boundary configuration.

HE Density Study (Elastic-Plastic)

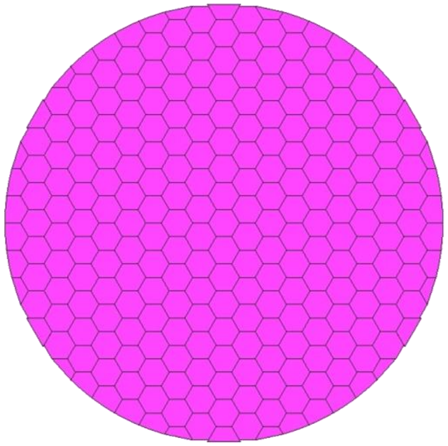


Load on sidewall depends more on boundary condition and less on yield strength of HE material

Thin wall stress approximation uses σ_c=175 ksi in required wall thickness calculation

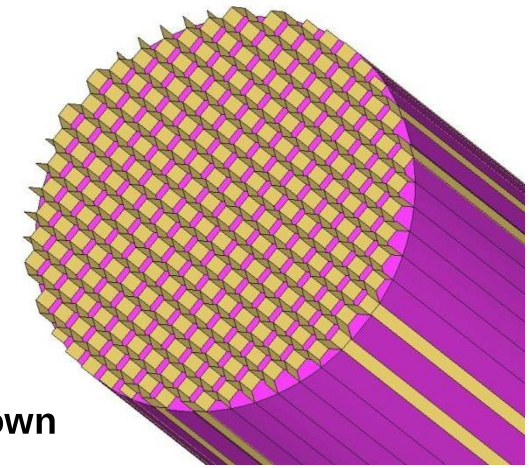
Honeycomb Reinforcement

CONCEPT: use a honeycomb structure to support/confine dense HE fill thereby limiting the load on the warhead sidewall.



Advantages
- Simple design and fabrication
- Honeycomb fragments are expected to be low collateral

Disadvantages
- Detonation wave propagation may be an issue
- Honeycomb (marginally) reduces payload volume
- Void formation in the HE will have to be managed



Warhead sidewall not shown

3D FE Model

Quasistatic FE Model

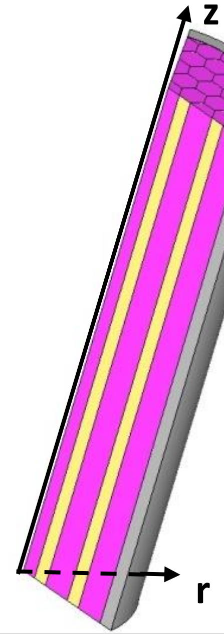
- 10 kG setback is prescribed
- The HE fill mesh is tied to the reinforcement mesh
- Cylindrical coordinate system is defined
- Symmetry is prescribed

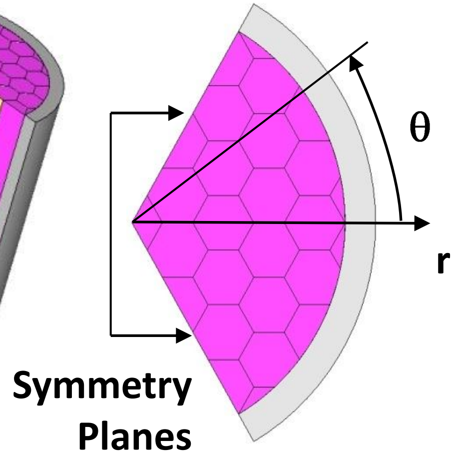
  $u(r, {}^{+}/{-}\ \theta_s, z) \cdot n_s = 0$
- Nodes located on warhead rear face are fixed

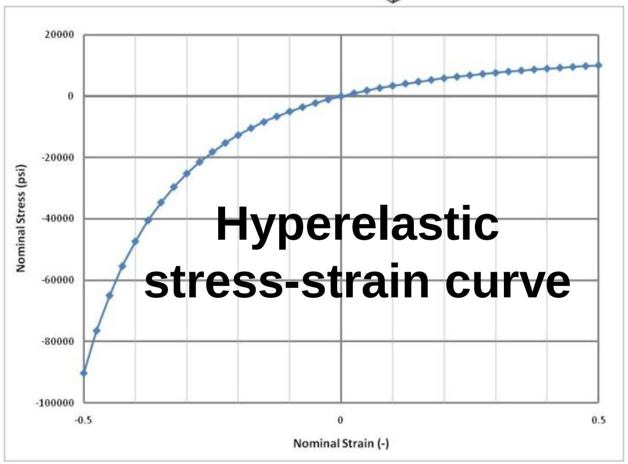
  $u(r,\theta,0) = (0,0,0)$
- Steel warhead material is linear elastic
- Aluminum reinforcement material is linear elastic and constitutive thickness is 1/32"
- Fill material is a dense, incompressible hyperelastic HE fill

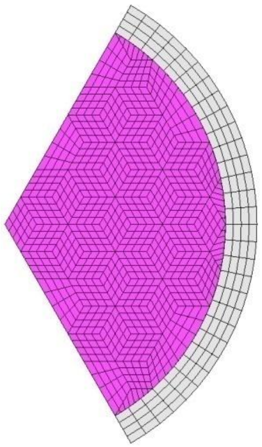
Two Configurations

- Tied – HE material is perfectly bonded to the warhead
- Sliding – slip is allowed between the HE material and the warhead

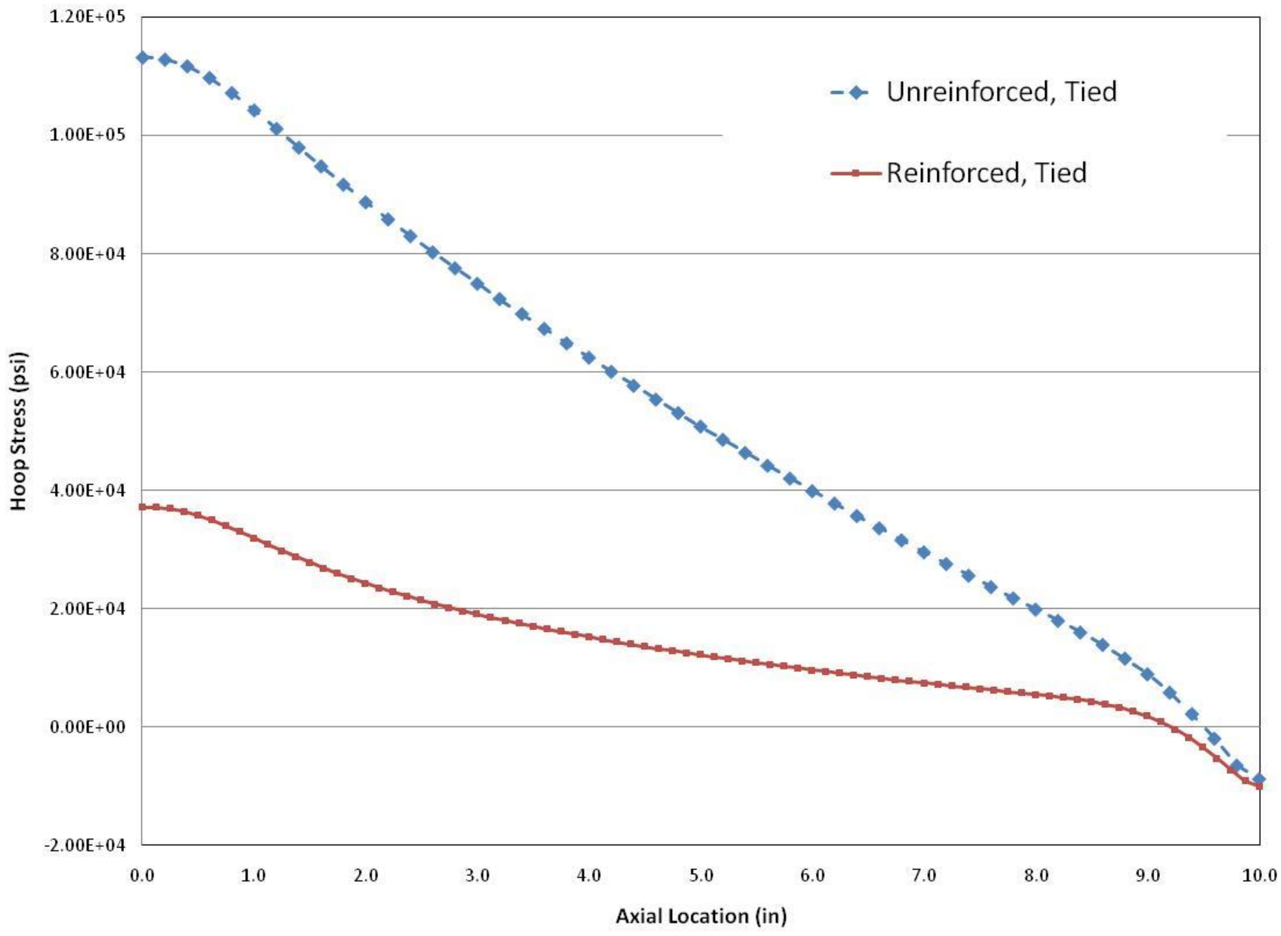






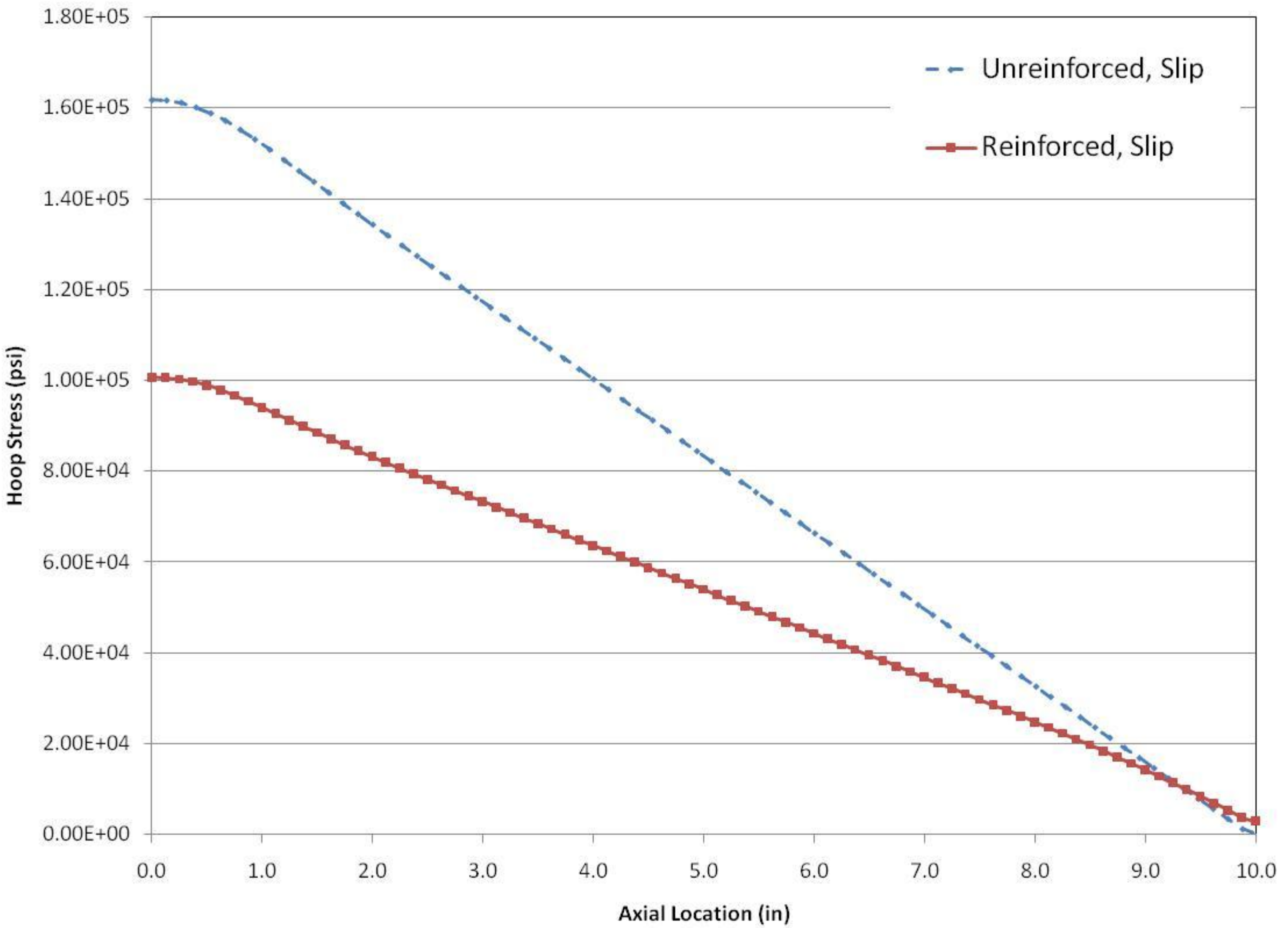


Tied FEM Hoop Stress Results



Reinforcement reduces maximum hoop stress by ~65%

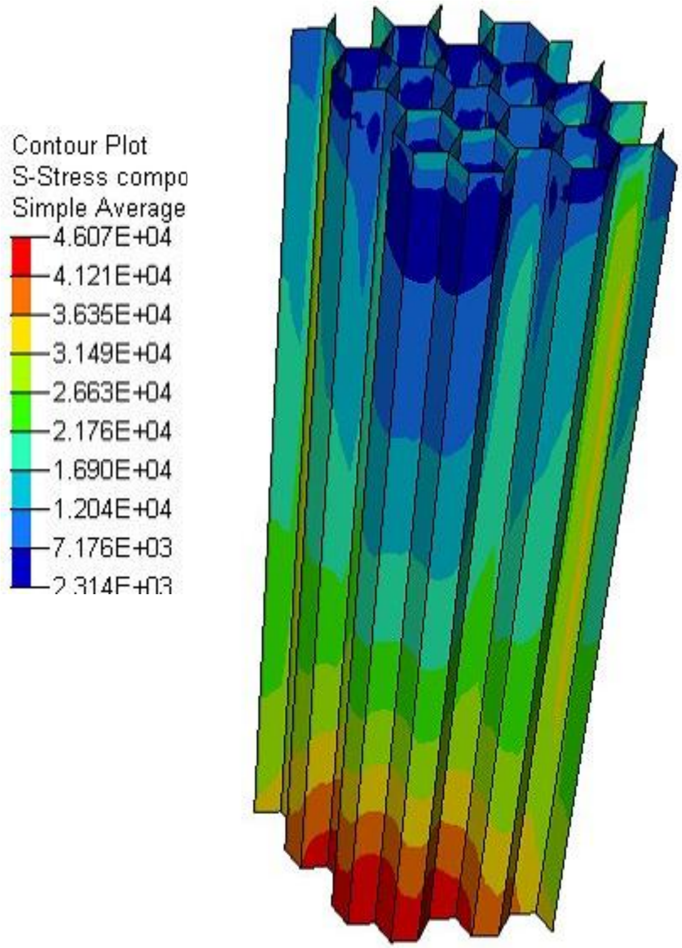
Sliding FEM Hoop Stress Results



Reinforcement reduces maximum hoop stress by ~38%

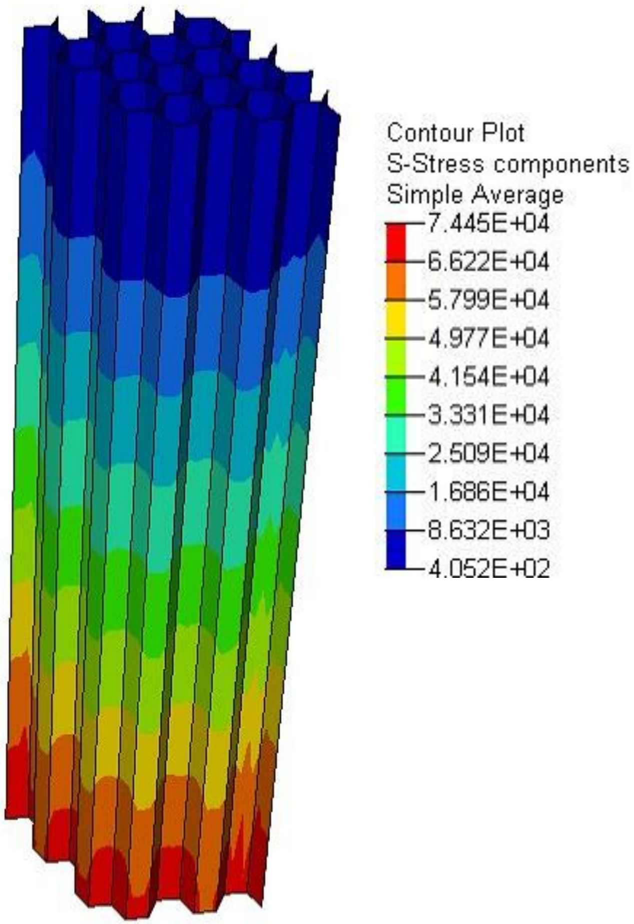
Reinforcement Structure von Mises Stress

HE Tied to Sidewall



von Mises stress is less than aluminum yield stress

HE Slides Relative to Sidewall

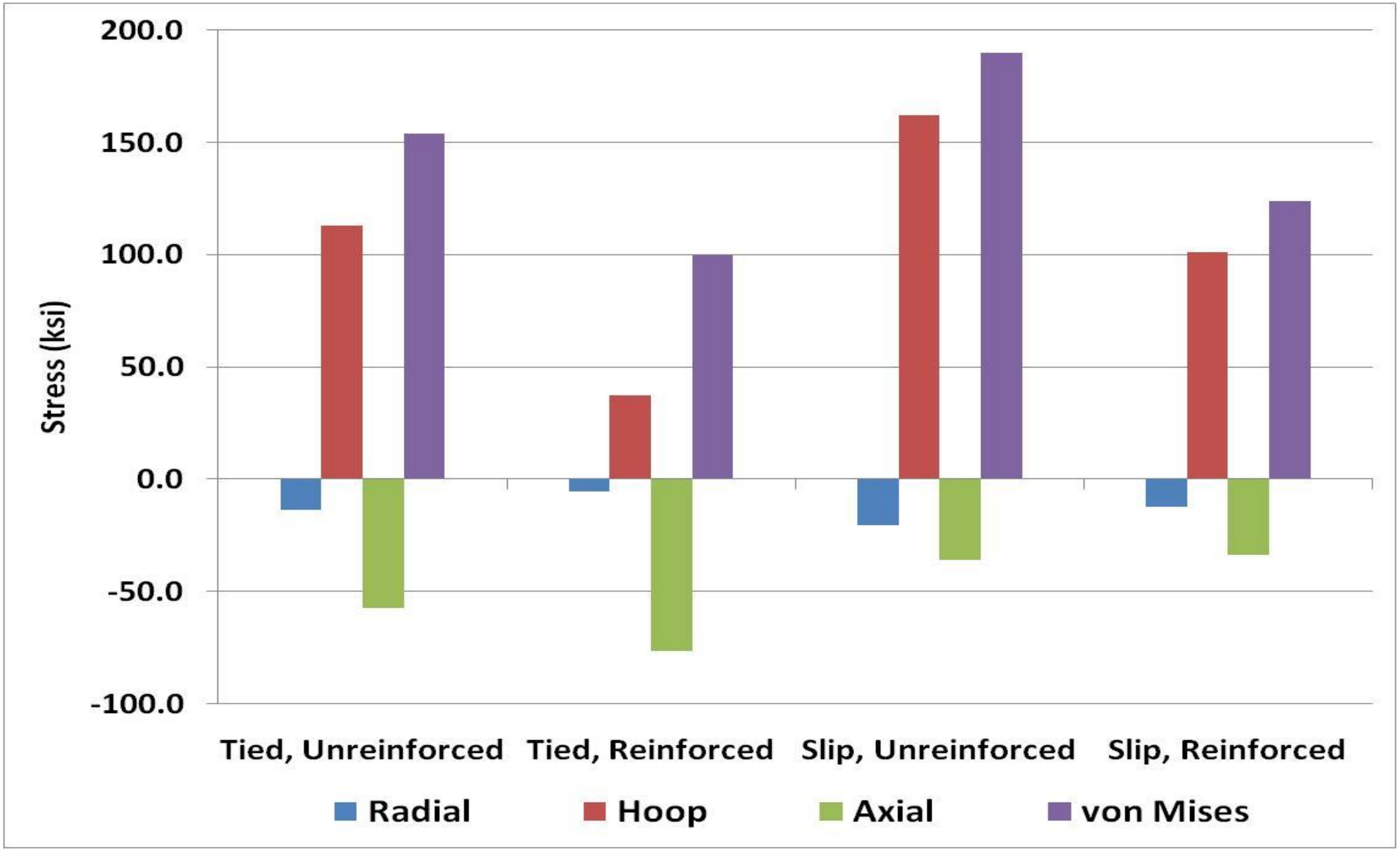


von Mises stress is approximately equal to the aluminum yield stress

HE is always tied to reinforcement structure

FEA Summary

Steel Sidewall Maximum Stress Values



Summary

The reinforcement analyses indicate that honeycomb is effective in reducing the loading on the warhead sidewall for both tied and sliding configurations

Cursory analyses investigating the effect of honeycomb material and cell wall thickness predict further reduction in the sidewall loading and increased structural integrity of the reinforcement

The design path forward exists and the loading resulting from the dense HE fill during gun launch can be managed.

Thank you.

Questions?

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